

APPENDIX E. SUPPORTING DATA FOR FISH AND CRAB PARAMETERIZATION

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1 Introduction

The purpose of this appendix is to provide details on the assumptions used in the parameterization of the fish and crab model compartments for the Lower Passaic River Study Area (LPRSA) bioaccumulation model. The remainder of this appendix is organized as follows:

- ◆ Section 2 – LPRSA data available for blue crab and the selected fish species evaluated in the LPRSA bioaccumulation model
- ◆ Section 3 – Comparison of diet fractions used in the bioaccumulation model with the diet fractions used in the LPRSA baseline ecological risk assessment (BERA)
- ◆ Section 4 – Evaluation of small forage fish abundance that was used to assign portions of small fish as prey for higher-trophic-level species
- ◆ Section 5 – References

2 Fish and Crab Data Used in the Bioaccumulation Model

The following section presents the LPRSA data used to support the bioaccumulation model.

2.1 OVERVIEW OF AVAILABLE LPRSA SAMPLES

LPRSA blue crab and fish tissue samples used for the calibration of the bioaccumulation model were collected during 2009 and 2010 sampling events (Windward 2018a, b). The database includes a mix of individual and composite samples:

- ◆ In August and September 2009, a large number of blue crab and fish representing numerous fish species were collected from the LPRSA (Windward 2010). Blue crab were analyzed as composites and fish were analyzed as composites or individual specimens, depending on the size of the fish.
- ◆ Between June and August 2010, small forage fish were collected from the LPRSA (Windward 2018b). Small forage whole-body fish specimens were analyzed as composites.

In addition, the LPRSA dataset includes samples analyzed as whole-body samples, as well as samples for which whole-body concentrations were mathematically calculated using samples of two different tissue types (i.e., reconstituted whole-body samples). For fish, whole-body samples were mathematically reconstituted using fillet and carcass weights and concentrations. For blue crab, whole-body samples were mathematically reconstituted using muscle/hepatopancreas and carcass weights and concentrations.

Table 1 summarizes the 2009/2010 LPRSA fish and blue crab samples. Of these samples, data from the following species were used in the bioaccumulation model calibration dataset: small filter-feeding fish (gizzard shad), small forage fish (various species), blue crab, carp, catfish, white perch, American eel, and bass.

Table 1. Summary of LPRSA fish and blue crab samples collected in 2009/2010 for species included in the bioaccumulation model

Model Compartment	Fish Species	Sample Type	Tissue Type			
			Fillet	Carcass	Whole Body (reconstituted)	Whole Body
Small filter-feeding fish	gizzard shad	composite	0	0	0	3
Small forage fish	mummichog	composite	0	0	0	18
	other small forage fish ^a	composite	0	0	0	9
Blue crab	blue crab	composite	0	24	24 ^b	0
Carp	carp	individual	12	0	0	12
Catfish	channel catfish	individual	11	11	11	0
	white catfish	individual	19	19	19	0

Model Compartment	Fish Species	Sample Type	Tissue Type			
			Fillet	Carcass	Whole Body (reconstituted)	Whole Body
White perch	white perch	individual	2	1	1	4
		composite	17	0	0	15
		total	19	1	1	19
Small American eel	american eel (< 50 cm)	individual	1	0	0	4
		composite	10	1	1	7
		total	11	1	1	11
Large American eel	american eel (> 50 cm)	individual	16	1	1	8
		composite	5	0	0	0
		total	21	1	1	8
Freshwater bass	largemouth bass	individual	2	2	2	0
		composite	1	1	1	0
		total	3	3	3	0
	smallmouth bass	composite	3	3	3	0

^a Value includes the following small forage fish samples: white perch (n = 2 samples), pumpkinseed (n = 1), silver shiner (n = 1), spottail shiner (n = 1), and mixed forage fish (n = 4).

^b Reconstituted whole-body tissue concentrations for blue crab were calculated using muscle/hepatopancreas and corresponding carcass concentrations. See details in Section 2.2.2.2.

LPRSA – Lower Passaic River Study Area

2.2 CALIBRATION DATASET

This section describes the data used to calibrate the bioaccumulation model for blue crab and each of the selected fish compartments. Section 3.3.4 of the main report presents a summary of the empirical data used for model calibration, and the complete dataset used in calibration is presented in Appendix F.

2.2.1 Assignment of samples to modeling areas

For each species included in the calibration dataset (i.e., small forage fish, blue crab, carp, catfish, white perch, American eel, and bass), each sample was assigned to one (or in some cases two) modeling areas for the model calibration dataset. Catch locations (see maps in Appendix F) were reviewed, and samples were assigned to the areas in which the fish were collected (e.g., a fish collected at river mile [RM 5.5] was assigned to the segment for RM 0 to RM 6). In addition, information regarding the foraging area and site fidelity for each species was evaluated, and a “boundary rule” based on typical movement (i.e., foraging area, not overall home range) was developed for each species. The boundary rule was then used to determine whether a given sample should be included in a second modeling area (i.e., Was the fish/crab in question likely to have been exposed to concentrations in a nearby modeling area?). For example, a fish collected at RM 5.5 was included in the RM 6 to RM 14.7 modeling area if the boundary rule for that species was 0.5 miles or greater.

Thus, based on a review of available information, the following boundary rules were used to develop the calibration dataset:

- ◆ A boundary rule of 0 miles was assigned to small forage fish.
- ◆ A boundary rule of 0.5 miles was assigned to blue crab, white perch, American eel (both size classes), and bass.
- ◆ A boundary rule of 1 mile was assigned to carp and catfish.

Details regarding the rationale for each of these boundary rules are presented in Table 2. In addition, Appendix F presents a sample-by-sample summary of the samples included in each of the modeling areas.

Table 2. Development of boundary rule

Model Group	Boundary Rule	Size of Foraging Area	Site Fidelity
Small forage fish	na (0 miles)	Small forage fish have been found to have an extremely limited foraging area contained to mudflats; a foraging area of 36 to 38 m was reported for adult forage fish (Lotrich 1975).	extremely high
Blue crab	0.5 miles	A limited foraging range was observed for blue crab during a six-month tag and recapture study. The high recapture rate within a 50-hectare embayment suggests that the primary home range of blue crab is relatively limited (Ramach et al. 2009). Based on the generally small movement of blue crab and knowledge regarding white perch habits (i.e., their tendency to stay in an area if feeding is good), site fidelity was assumed to be high.	high
Carp	1 mile	Stuart and Jones (2002) reported a home range of 2.8 km for carp. A later study (Jones and Stuart 2007) reported that after 9 months, 66% of tagged carp were recaptured < 1 km from the release site and 80% were recaptured < 5 km from the release site. Based on this somewhat larger range and the ability of carp to move greater distances, site fidelity was assumed to be moderate.	moderate
Catfish	1 mile	In a tag and recapture study along the Wisconsin and Anacostia Rivers, catfish were reported to have been recaptured 2 to 8 km from their release sites (CSWRCB 2011). Based on this somewhat larger range and the ability of catfish to move greater distances, site fidelity was assumed to be moderate.	moderate
White perch	0.5 miles	White perch were reported to have an average movement of 1.4 km during a 21-day study (McGrath 2005). Based on the generally limited movement of perch and knowledge regarding white perch habits (i.e., their tendency to stay in an area if feeding is good), site fidelity was assumed to be high.	high
American eel (both sizes)	0.5 miles	American eel have been reported to have limited foraging ranges. Ranges of 0.38 to 17 hectares were observed in short- and long-term tag and recapture studies (Thibault et al. 2007; Morrison and Secor 2003), with no difference in range according to eel size class (Ford and Mercer 1986). Based on this information and knowledge regarding eel habits (i.e., their tendency to stay in an area if feeding is good), site fidelity was assumed to be high.	high
Bass	0.5 miles	Bass have been found to have extremely limited foraging area, ranging from 30 to 68 m for smaller individuals (Lewis and Flickinger 1967) and 60 to 120 m for larger individuals (Curtis and Wehrly 2006). Based on this information and knowledge regarding bass habits (i.e., their tendency to stay in an area if feeding is good), site fidelity was assumed to be high.	high

na – not applicable

2.2.2 Species-specific dataset details

This section presents details of the samples used for the bioaccumulation model calibration set for the following species: small forage fish, blue crab, carp, catfish, white perch, American eel, freshwater bass, and filter-feeding fish. Section 3.3.4 of the main report presents a summary of the empirical data used for model calibration, and the complete dataset used in calibration is presented in Appendix F.

2.2.2.1 Small forage fish

The small forage fish compartment of the bioaccumulation model includes primarily mummichog (*Fundulus heteroclitus*), but it also includes other species, such as shiners (*Notropis* spp.), striped mullet (*Mugil cephalus*), and tessellated darter (*Etheostoma olmstedi*). Composite samples of small forage fish were analyzed for a number of species: mummichog (n = 18), gizzard shad (n = 3), pumpkinseed (n = 1), silver shiner (n = 1), spottail shiner (n = 1), white perch (n = 2), and mixed forage fish (n = 4). Mixed forage fish samples were composed of multiple small forage fish species (Table 3).

Table 3. Composition of mixed forage fish samples

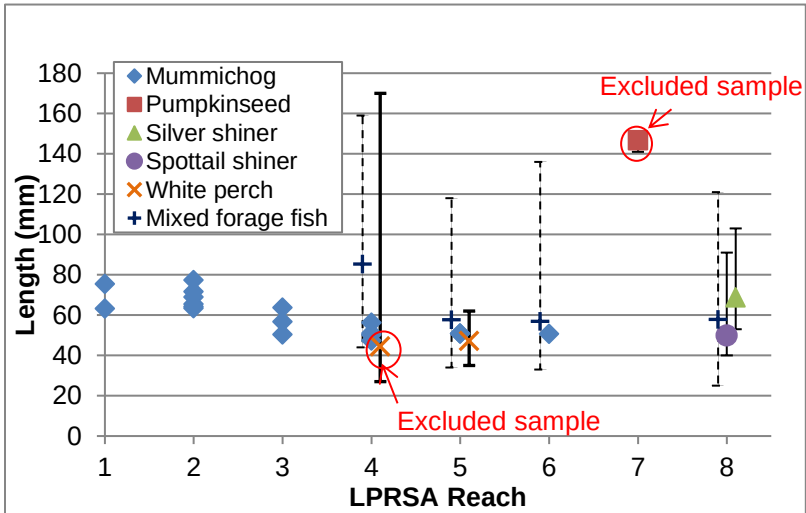
Sample ID	No. of Fish in Sample	Reach	RM	Fish Species
LPR4-MXWB-Comp01	26	4	7.0	smallmouth bass (n = 1), striped bass (n = 2), tessellated darter (n = 4), striped mullet (n = 2), gizzard shad (n = 10), spottail shiner (n = 6), and Atlantic silverside (n = 1)
LPR5-MXWB-Comp02	69	5	8.4	striped mullet (n = 1), white perch (n = 45), gizzard shad (n = 15), spottail shiner (n = 7), and inland silverside (n = 1)
LPR6-MXWB-Comp03	74	6	11.2	striped bass (n = 5), bluegill (n = 9), striped mullet (n = 5), white perch (n = 48), and Atlantic silverside (n = 7)
LPR8-MXWB-Comp04	18	8	14.2	smallmouth bass (n = 2), striped bass (n = 1), gizzard shad (n = 4), and inland silverside (n = 11)

ID – identification

RM – river mile

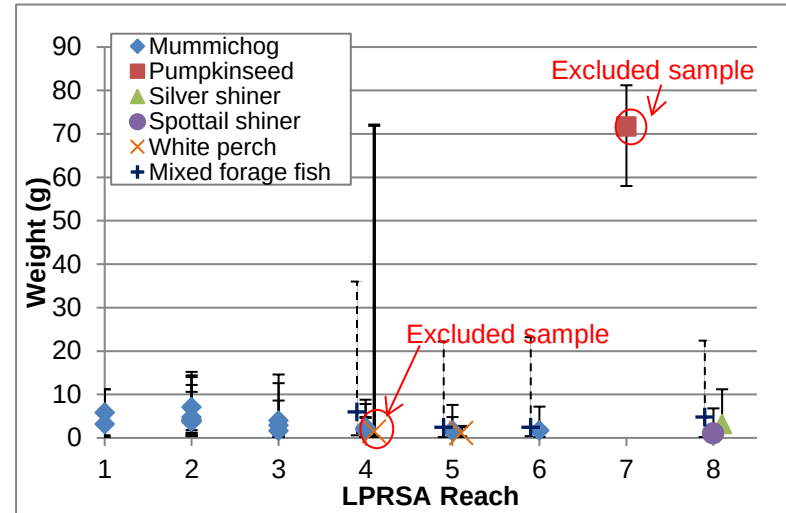
The small forage fish data used to calibrate the bioaccumulation model included only those fish samples that represented fish small enough to be preyed upon by other LPRSA fish and that were generally benthic-feeding fish. Gizzard shad, although collected under the 2010 small forage fish sampling effort (Windward 2018b), were excluded from the bioaccumulation calibration dataset for small forage fish because this species is more representative of filter-feeding fish, which were modeled as a separate compartment in the bioaccumulation model (see Section 2.3 for discussion of filter-feeding fish data). In addition, larger fish collected during the 2010 small forage fish sampling effort that did not represent appropriate prey for modeled LPRSA fish-eating fish were not included in the calibration dataset for small forage fish (Figures 1a and 1b). Such samples included the single pumpkinseed composite sample (composed of three fish ranging from 141 to 150 mm in length) and one of the two

white perch samples, which included 1 large fish (170 mm in length) and 120 smaller fish (ranging from 27 to 57 mm in length).



Note: Bars represent minimum and maximum values in composite sample.

Figure 1a. Mean length of small forage fish in analytical samples by LPRSA reach



Note: Bars represent minimum and maximum values in composite sample.

Figure 1b. Mean weight of small forage fish in analytical samples by LPRSA reach

2.2.2.2 Blue crab

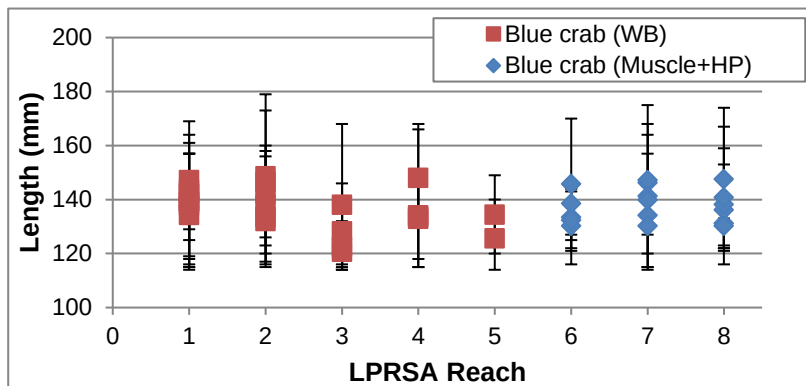
LPRSA Empirical Dataset

Blue crab were analyzed as composite samples of one or more of the following tissue types: muscle/hepatopancreas, carcass (i.e., non-muscle/hepatopancreas), muscle-only, or hepatopancreas-only samples. Paired carcass and muscle/hepatopancreas samples were collected from the same blue crab composite samples in Reaches 1 through 5 (RM 0 to RM 10), and reconstituted whole-body concentrations (n = 24) were calculated for paired muscle/hepatopancreas and carcass samples for use in the bioaccumulation model calibration dataset. No carcass samples were analyzed above RM 10, although 17 muscle/hepatopancreas crab samples were analyzed above RM 10. Table 4 presents a summary of the number of available samples for each tissue type by reach and Figures 2a and 2b presents the sizes of blue crabs included in composite samples.

Table 4. Number of crab tissue samples by tissue type and reach

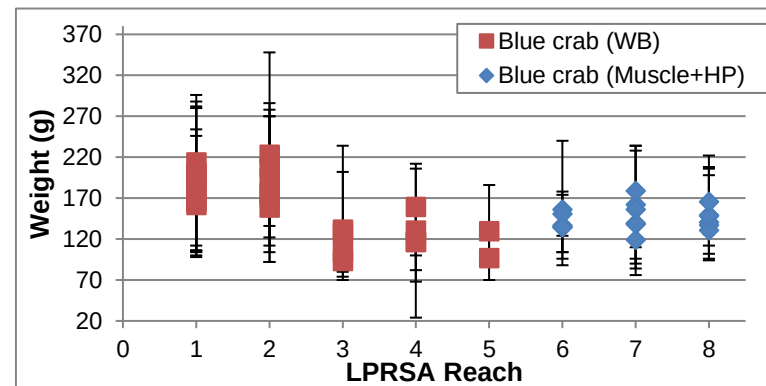
Tissue Type	Number of Samples								Total
	Reach 1 (RM 0 to RM 2)	Reach 2 (RM 2 to RM 4)	Reach 3 (RM 4 to RM 6)	Reach 4 (RM 6 to RM 8)	Reach 5 (RM 8 to RM 10)	Reach 6 (RM 10 to RM 12)	Reach 7 (RM 12 to RM 14)	Reach 8 (RM 14 to RM 17.4)	
Carcass	8	6	4	4	2	-	-	-	24
Hepatopancreas only	2	2	1	-	-	-	1	1	7
Muscle only	5	4	2	-	1	3	3	3	21
Muscle/hepatopancreas	8	6	4	4	2	5	6	6	41
Whole body (calculated)	8	6	4	4	2	-	-	-	24
Whole body (estimated based on regression)	-	-	-	-	-	5	6	6	17

RM – river mile



Note: Bars represent minimum and maximum values in composite sample.

Figure 2a. Mean length of blue crab in analytical composite samples



Note: Bars represent minimum and maximum values in composite sample.

Figure 2b. Mean weight of blue crab in analytical composite samples

Development of Regressions to Estimate Blue Crab Whole-body Concentrations

As Table 4 demonstrates, the LPRSA bioaccumulation model calibration dataset includes 24 calculated whole-body blue crab samples, all from crabs collected below RM 10. No carcass samples were analyzed for Reaches 6 through 8, so whole-body concentrations could not be calculated.

To better evaluate the performance of the bioaccumulation model for blue crab above RM 10, regressions were developed relating the concentrations in the muscle/hepatopancreas tissue samples to the calculated whole-body concentrations ($n = 24$) for samples collected between RM 0 and RM 10 ($n = 24$). These regressions were then used to estimate whole-body concentrations based on the 17 muscle/hepatopancreas samples available above RM 10 (for Reaches 6 through 8).

Linear regressions were developed for the three primary calibration chemicals evaluated using the bioaccumulation model: 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), tetraCB, and 1,2,3,4,6,7,8-heptachlorodibenzofuran (HpCDF). Because initial attempts to develop regressions found that linear regressions were a good fit to the data (i.e., r^2 generally > 0.9), log-normalized transformation was not used, thereby avoiding calculation complications that occur when back-transformation is needed. Table 5 and Figures 3a through 3c present a summary of the regressions used to describe the relationship between muscle/hepatopancreas tissues and whole-body tissue concentrations.

Table 5. Regressions to calculate whole-body tissue from muscle/hepatopancreas tissues for target chemicals

Chemical	r^2	Selected Regression Equation	Figure
2,3,7,8-TCDD	0.95	$C_{\text{whole-body}} = 0.7101 \times C_{\text{muscle/hepatopancreas}} + 8.1878$	Figure 3b
TetraCB	0.88	$C_{\text{whole-body}} = 0.701 \times C_{\text{muscle/hepatopancreas}} + 10.322$	Figure 3c
1,2,3,4,6,7,8-HpCDF	0.93	$C_{\text{whole-body}} = 0.7697 \times C_{\text{muscle/hepatopancreas}} + 0.7999$	Figure 3a

HpCDF – heptachlorodibenzofuran

TCDD – tetrachlorodibenzo-*p*-dioxin

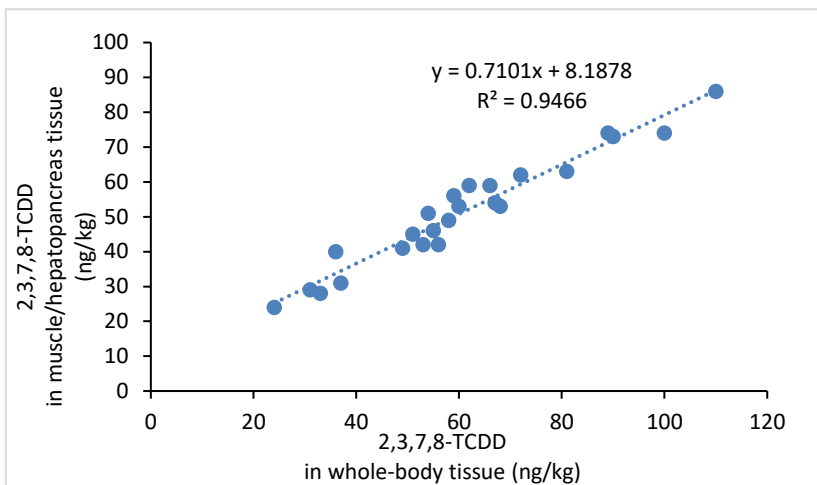


Figure 3a. 2,3,7,8-TCDD linear regression for blue crab

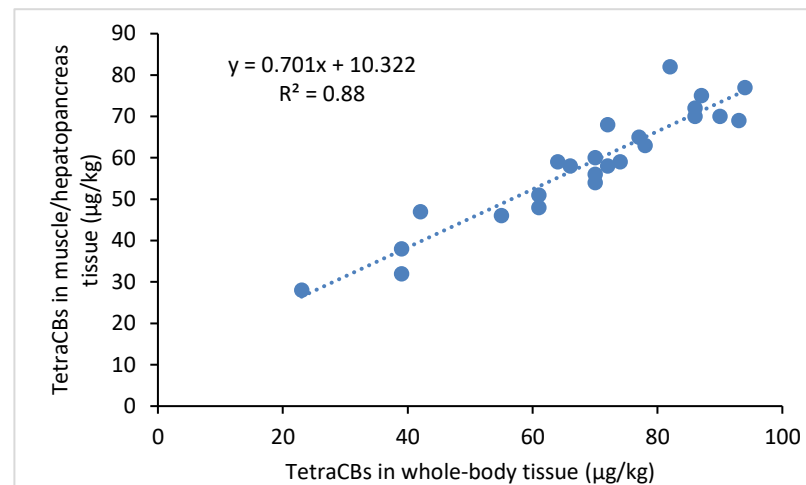


Figure 3b. TetraCB linear regression for blue crab

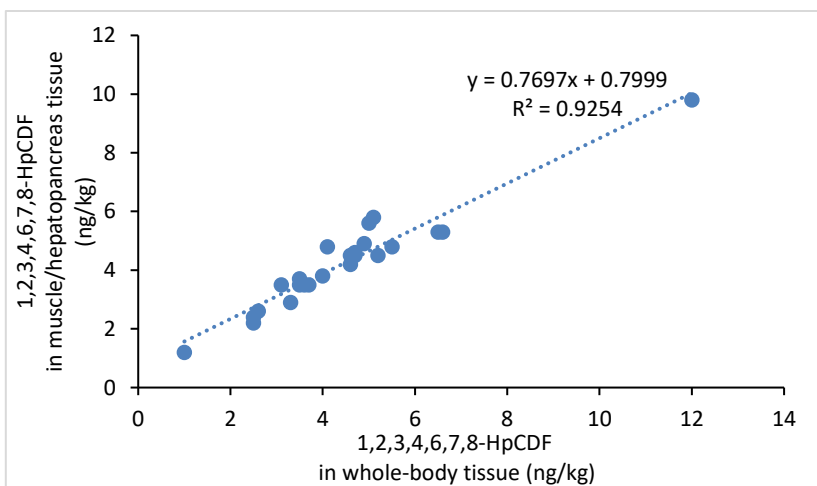


Figure 3c. 1,2,3,4,6,7,8-HpCDF linear regression for blue crab

2.2.2.3 Carp

Carp (*Cyprinus carpio*) are modeled in a compartment separate from benthic omnivores/invertivores (catfish) in the bioaccumulation model, because carp represent a unique exposure pathway based on their size, age, and feeding ecology.

Carp tissue data were analyzed as individual fish collected from LPRSA Reaches 3 through 8 (RM 4 to RM 17.4). Both carp fillet and whole-body samples were collected (from different fish) and analyzed.¹ Carp analyzed as fillets were generally larger (in length and weight) than those analyzed as whole-body samples (Figures 4a and 4b). Two carp samples collected between RM 5 and RM 6 in Reach 3 were included in the calibration dataset because, although they were collected outside of the modeling area identified for carp (see main text, Section 3.2.5), the majority of the exposure for these fish is expected to have been within the modeling area.

¹ For some other LPRSA fish for which fillets were analyzed, the fillet and carcass data were derived from the same fish, and these data were mathematically reconstituted to derive whole-body concentration data.

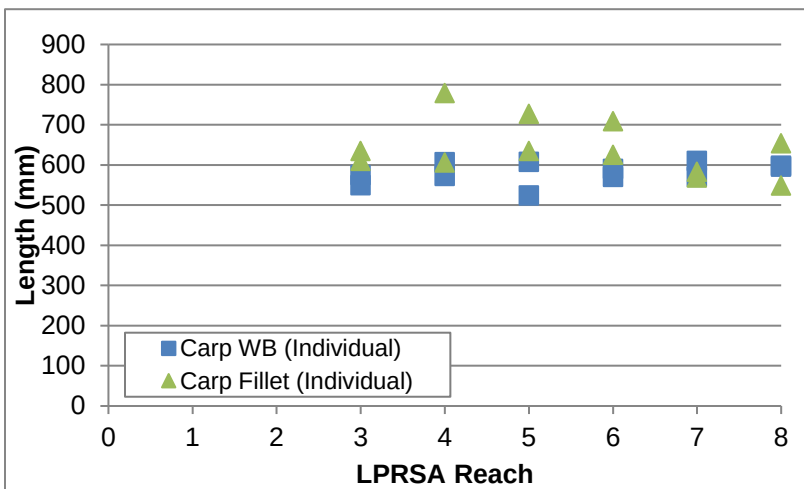


Figure 4a. Length of individual carp in analytical samples by LPRSA reach

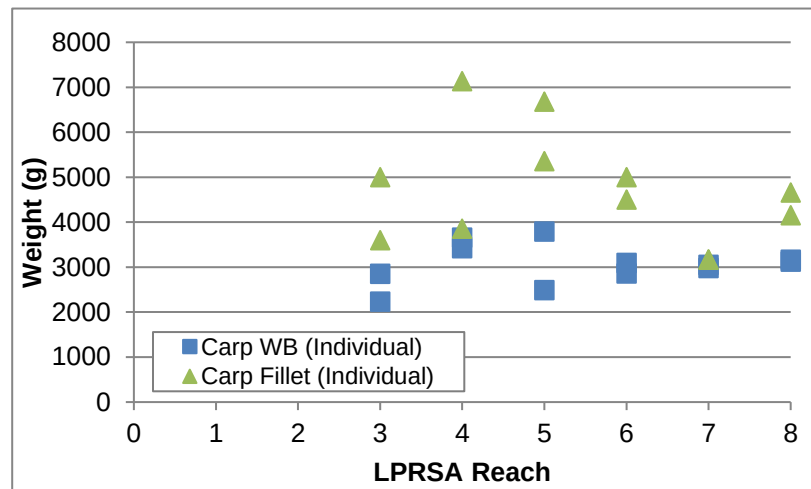


Figure 4b. Weight of individual carp in analytical samples by LPRSA reach

2.2.2.4 Catfish

The catfish compartment of the bioaccumulation model included both white catfish (*Ictalurus catus*) and channel catfish (*Ictalurus punctatus*). These catfish species have similar life histories and diets. In addition, the channel and white catfish collected in the LPRSA were similar in size (see Figures 5a and 5b). Both channel and white catfish are opportunistic feeders that prey on whatever is available, including larger invertebrates such as amphipods, crayfish, and mollusks, as well as insects and small fish (NJDEP 2001; Wellborn 1988; California Fish Website 2013a; Turner 1966b). Both white and channel catfish are predominately benthic feeders that consume some portion of sediment and detritus in their diets. Channel catfish have a lower tolerance for salinity than do white catfish and therefore may have a smaller exposure area within the LPRSA than do white catfish. White catfish were collected in lower areas of the LPRSA (below RM 8²), where there is higher salinity.

Only white and channel catfish whole-body (i.e., reconstituted) data were evaluated in the bioaccumulation model calibration. Catfish whole-body data were based on the analysis of individual fish for both fillet and carcass tissue. Whole-body concentrations were mathematically reconstituted based on the fillet and carcass weights and concentrations.

² LPRSA Reach 5 extends from RM 8 to RM 10.

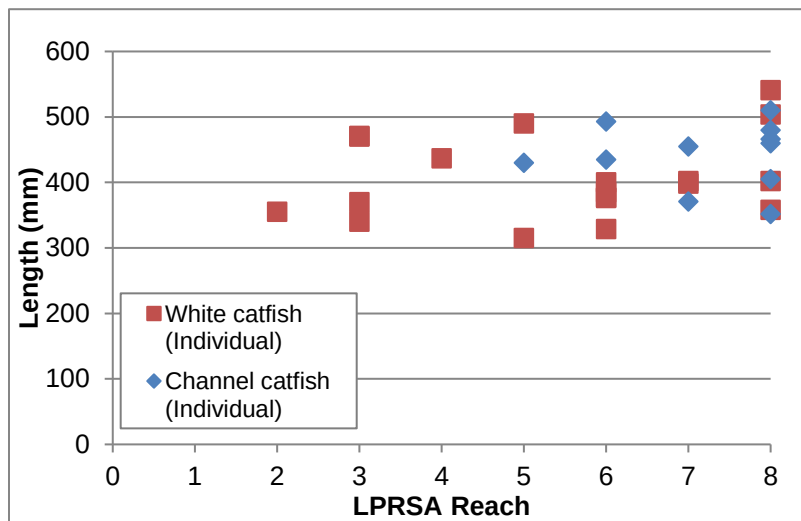


Figure 5a. Length of individual catfish in analytical samples by LPRSA reach

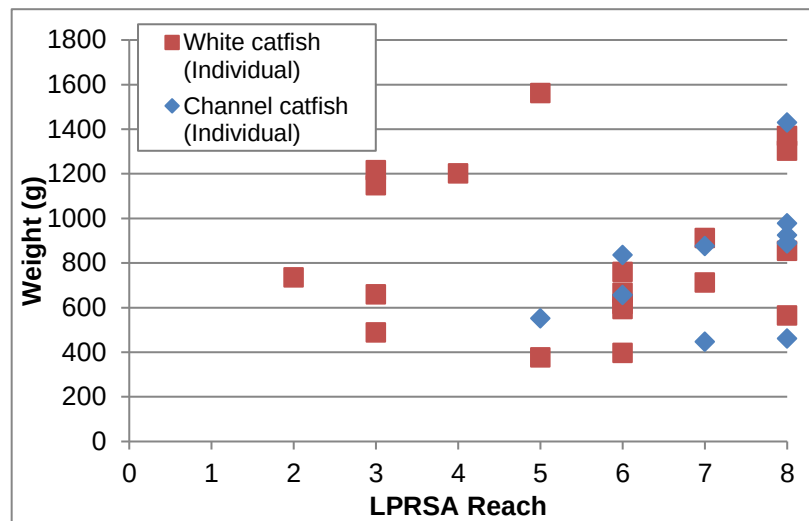


Figure 5b. Weight of individual catfish in analytical samples by LPRSA reach

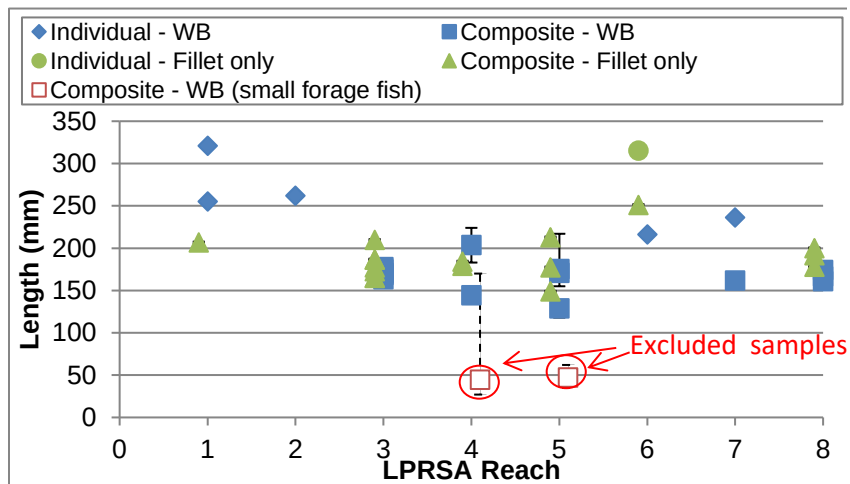
2.2.2.5 White perch

White perch (*Morone americana*) are included in the bioaccumulation model to represent small invertivorous fish. White perch tissue data were analyzed as individual fish and fish composites for white perch collected throughout the LPRSA; individual and composite samples were analyzed one of three ways:

- ◆ Fillet-only samples
- ◆ Fillet and carcass samples (analytical results used to mathematically reconstitute whole-body concentrations)
- ◆ Whole-body samples

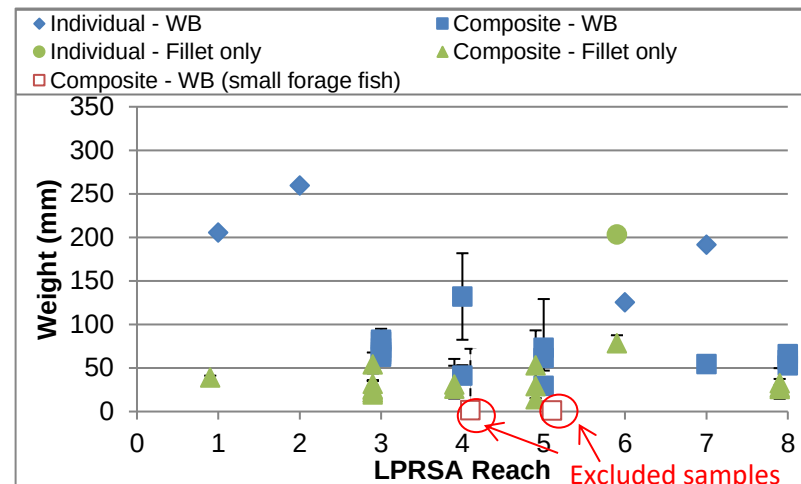
White perch analyzed as fillet-only samples were generally within the size range (in length and weight) of white perch analyzed as whole-body samples (Figures 6a and 6b). Only white perch whole-body data were used in the bioaccumulation model calibration, although Figures 6a and 6b show fish sizes for fillet data for informational purposes. The two white perch samples analyzed as part of the 2010 small forage fish collection effort (Windward 2018b) were not included in the white perch calibration dataset,³ because these samples were based on white perch that were much smaller in size than the white perch collected in 2009 (Windward 2018a) (see Figures 6a and 6b). The white perch collected in 2009 are thought to better represent the size of perch caught and consumed by people. Whole-body data from both the whole-body samples and the reconstituted fillet and carcass samples were used in the bioaccumulation model.

³ Only one of the two white perch composite samples collected during the 2010 small forage fish sampling event was included in the small forage fish calibration dataset (Section 2.2.2.1); the other sample was excluded given the wide range of fish sizes included in the composite.



Note: Bars represent minimum and maximum values in composite sample. .

Figure 6a. Length of white perch in analytical samples by LPRSA reach



Note: Bars represent minimum and maximum values in composite sample.

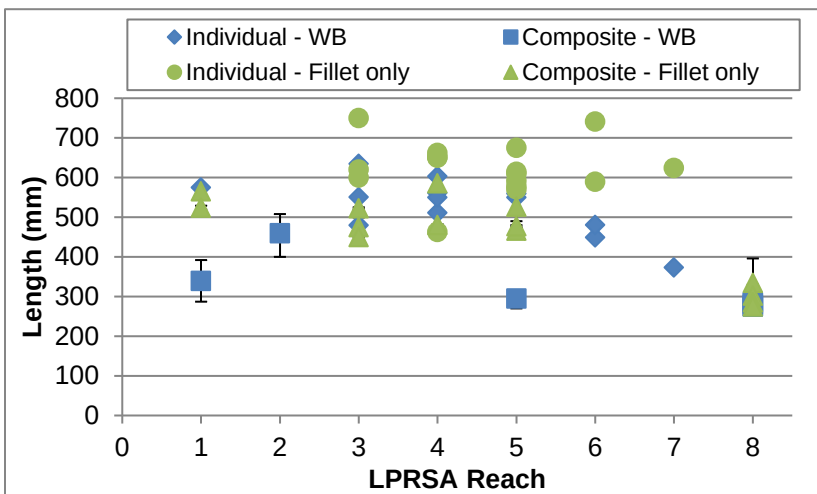
Figure 6b. Weight of white perch in analytical samples by LPRSA reach

2.2.2.6 American eel

American eel (*Anguilla rostrata*) were included in the bioaccumulation model to represent piscivorous fish found throughout the LPRSA. Like white perch data, American eel tissue data were analyzed based on individual fish and fish composites collected throughout the LPRSA; individual and composite samples were analyzed one of three ways:

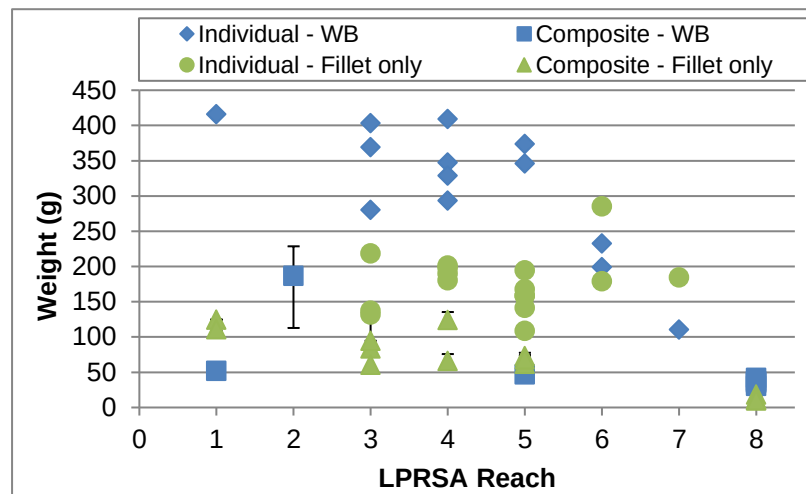
- ◆ Fillet-only samples
- ◆ Fillet and carcass samples (analytical results used to mathematically reconstitute whole-body concentrations)
- ◆ Whole-body samples

American eel analyzed as fillet-only samples were generally similar in length but greater in weight than American eel analyzed as whole-body samples (Figures 7a and 7b). Only American eel whole-body data were used in the bioaccumulation model calibration, although Figures 7a and 7b show fish sizes for fillet data for informational purposes. Whole-body data from both the whole-body samples and the reconstituted fillet and carcass samples were used in the bioaccumulation model. All available American eel whole-body data were used, with two size classes (i.e., < 50 cm and > 50 cm) evaluated in the bioaccumulation model.



Note: Bars represent minimum and maximum values in composite sample.

Figure 7a. Length of American eel in analytical samples by LPRSA reach



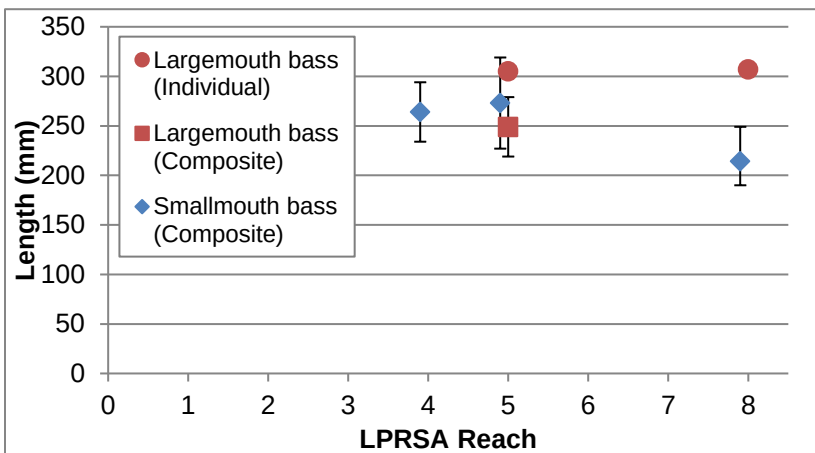
Note: Bars represent minimum and maximum values in composite sample.

Figure 7b. Weight of American eel in analytical samples by LPRSA reach

2.2.2.7 Freshwater bass

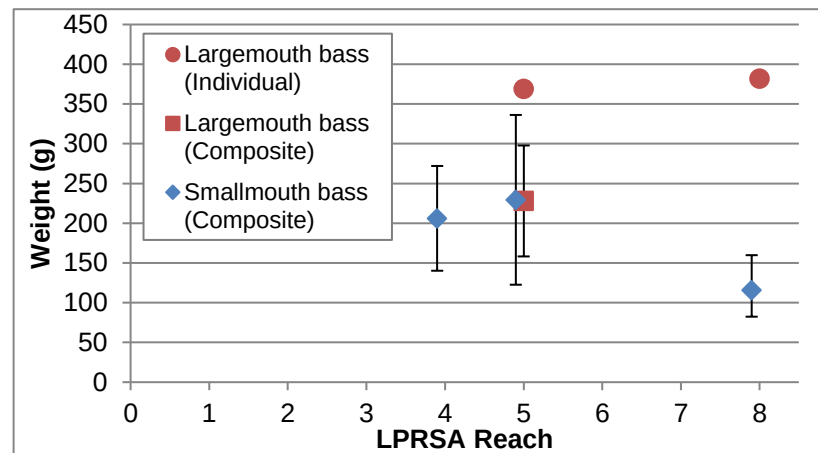
The freshwater bass compartment of the bioaccumulation model includes both smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*). Smallmouth and largemouth bass have similar life histories and diets. Both are opportunistic feeders and primarily feed on small fish and invertebrates based on their availability (George and Hadley 1979; Turner 1966a; Wydoski and Whitney 1979). In addition, smallmouth and largemouth bass collected in the LPRSA for analysis were generally similar in size (Figures 8a and 8b). Both were limited to the upper portion (above RM 6) of the LPRSA.

Available smallmouth and largemouth bass whole-body data were evaluated in the bioaccumulation model calibration; however, data were limited to three smallmouth and three largemouth bass whole-body samples. Freshwater bass whole-body (both fillet and carcass tissue) data were based on the analysis of individual fish or fish composites (composed of two or three fish). Whole-body concentrations that had been mathematically reconstituted based on fillet and carcass weights and concentrations were used in the bioaccumulation model.



Note: Bars represent minimum and maximum values in composite sample.

Figure 8a. Length of freshwater bass in analytical samples by LPRSA reach



Note: Bars represent minimum and maximum values in composite sample.

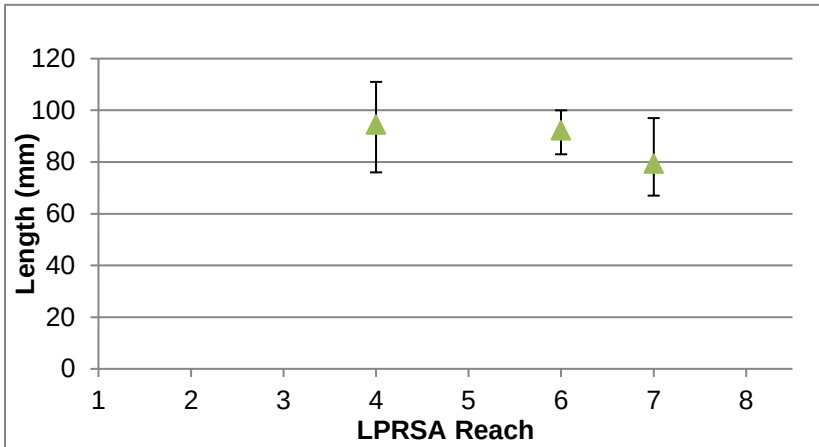
Figure 8b. Weight of freshwater bass in analytical samples by LPRSA reach

2.2.2.8 Small filter-feeding fish

The small filter-feeding fish compartment of the bioaccumulation model includes juvenile (young-of-the-year) Atlantic menhaden (*Brevoortia tyrannus*) and small gizzard shad (*Dorosoma cepedianum*). Limited LPRSA data were available for filter-feeding fish; three whole-body composite samples of small gizzard shad were collected during the 2010 small forage fish sampling effort (Windward 2018b). LPRSA data were available for adult Atlantic menhaden but not for juvenile Atlantic menhaden. Because current data were limited, filter-feeding fish data were not a primary target for calibration of the bioaccumulation model; however, these data were evaluated to estimate how well small filter-feeding fish tissue concentrations were estimated.

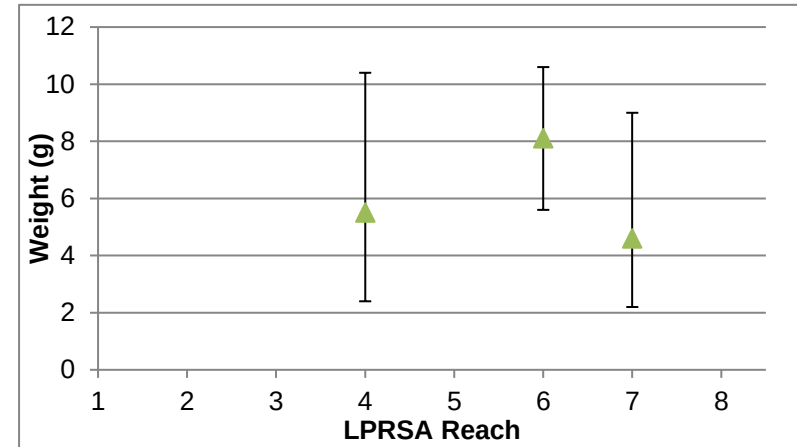
Figures 9a and 9b present data on the mean length and weight, respectively, of fish analyzed in the gizzard shad composite samples; individual fish ranged from 67 to 111 mm in length. Juvenile Atlantic menhaden data for the LPRSA were not available; however, in the general literature, juvenile Atlantic menhaden have been reported to range from 55 to 140 mm in length (Rogers and van den Avyle 1989), which is a range similar to the lengths of fish collected in the LPRSA. Gizzard shad and adult Atlantic menhaden dioxin/furan and PCB data⁴ from the LPRSA 1999 sampling effort were available (BBL 2001); however, these fish were not expected to represent the size of fish consumed by higher trophic levels.

⁴ Atlantic menhaden caught during the 1999 sampling effort at LPRSA locations were an average of 342 mm long in Reach 1 and 304 mm long in Reach 3 (BBL 2001). Atlantic menhaden caught during the 2009 and 2010 fish community surveys (n = 149 fish with reported size data) ranged from 80 to 390 mm in length; only 3 of the fish were < 270 mm long.



Note: Bars represent minimum and maximum values in composite sample.

Figure 9a. Mean length of gizzard shad in analytical composite samples



Note: Bars represent minimum and maximum values in composite sample.

Figure 9b. Mean weight of gizzard shad in analytical composite samples

3 Comparison of Diet Assumptions with with BERA

For the species or species groups included in the bioaccumulation model and/or evaluated in the LPRSA BERA (Windward 2019), diets were assigned based on a review of regional and general scientific literature (see main text, Section 3.3).

For species for which diets were used in both the bioaccumulation model and the evaluation of risks in the BERA, diets were developed to be consistent with one another. However, the ways in which these diets were applied in the BERA (Windward 2019) and the bioaccumulation model were somewhat different for the following reasons:

- ◆ **Limited species for which empirical data were available** – For the BERA (Windward 2019), dietary components were limited to those prey types for which empirical LPRSA chemistry data were available (i.e., sediment, benthic invertebrate [worm] tissue from bioaccumulation testing, blue crab tissue, and fish tissue). Dietary components for the bioaccumulation model were limited to the modeled species/species groups, which included a wider range of potential prey items (e.g., particulates/detritus, phytoplankton/algae, and zooplankton) and specific invertebrate compartments (i.e., small benthic invertebrate deposit feeders [DEP], small benthic invertebrate detritivores [DET], and benthic invertebrate carnivores/omnivores [C/O]) with estimated concentrations.
- ◆ **Ability to incorporate ranges in the bioaccumulation model** – Although the bioaccumulation model used point estimates (i.e., nominal values) for prey portions, as did the BERA (Windward 2019), the bioaccumulation model also involved the development of ranges for each prey item. These ranges were intended to account for both the uncertainty of the assigned percentages (given the site-specific opportunistic feeding behavior of fish) and the variability of the diets depending on prey availability (i.e., the season and specific location within the LPRSA of a given fish may result in a significantly different diet).
- ◆ **Inclusion of sediment in the diet** – The bioaccumulation model included sediment (as sediment solids or particulate/detritus) as a component of the diet; in the BERA, sediment was incorporated as an incidentally ingested portion in addition to dietary estimates from prey tissue. Particulate/detritus was not a prey portion that could be explicitly included in the LPRSA BERA dietary calculations, because empirical chemical concentration data were not available for particulates/detritus, and (as noted) only empirical data were used to derive dietary concentrations for the BERA (Windward 2019).

The dietary assumptions for fish and blue crab are summarized in Table 6. A detailed rationale for the development of these diets is presented in Table 7.

Table 6. General comparison of BERA and bioaccumulation model fish prey composition

Fish Species	Dietary Items and Portions		Notes
	LPRSA BERA	LPRSA Bioaccumulation Model	
Filter-feeding fish	species not evaluated in BERA	50% particulates/detritus 25% phytoplankton/algae 25% zooplankton	na
Small forage fish (mummichog)	100% worms	1% sediment solids 15% particulates/detritus 15% phytoplankton/algae 4% zooplankton 65% benthic invertebrates	Of the species with available empirical data for the BERA, only worms were appropriate as a dietary item for small forage fish. In the BERA, estuarine and freshwater worms were, in part, used as a surrogate for the consumption of benthic invertebrates and, to a lesser extent, particulates/detritus and phytoplankton/algae. In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.
American eel < 50 cm	80% worms 10% blue crab 10% small fish	2% sediment solids 3% particulates/detritus 85% benthic invertebrates 10% small fish	Diets included the same portion of small fish (< 13 cm). The invertebrate portion of the diet in the BERA (worms and blue crab) was, in part, used as a surrogate for the consumption of benthic invertebrates and, to a lesser extent, particulates/detritus. In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.
Blue crab	species not evaluated in BERA through a dietary pathway	2% sediment solids 1% particulates/detritus 83% benthic invertebrates 14% small fish	na
Carp	82% worms 17% blue crab 1% small fish	15% sediment solids 25% particulates/detritus 5% phytoplankton/algae 54% invertebrates 1% small fish	Diets included the same portion of small fish (< 11 cm). The invertebrate portion of the diet in the BERA (worms and blue crab) was, in part, used as a surrogate for the consumption of benthic invertebrates and insects and, to a lesser extent, particulates/detritus and phytoplankton/algae. In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.
Catfish	channel and white catfish specifically evaluated in BERA: 55% worms 5% blue crab 40% small fish	5% sediment solids 10% particulates/detritus 2% phytoplankton/algae 43% benthic invertebrates 40% small fish	Diets included the same portion of small fish (< 13 cm). The invertebrate portion of the diet in the BERA (worms and blue crab) was, in part, used as a surrogate for the consumption of insects and benthic invertebrates and, to a lesser extent, particulates/detritus and phytoplankton/algae. In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.
White perch	70% worms 15% blue crab 15% small fish	5% particulates/detritus 2% phytoplankton/algae 3% zooplankton 75% benthic invertebrates 15% small fish	Diets included the same portion of small fish (< 11 cm). The invertebrate portion of the diet in the BERA (worms and blue crab) was, in part, used as a surrogate for the consumption of invertebrates and, to a lesser extent, particulates/detritus, and phytoplankton/algae.

Fish Species	Dietary Items and Portions		Notes
	LPRSA BERA	LPRSA Bioaccumulation Model	
American eel > 50 cm	35% worms 25% blue crab 40% small fish	2% sediment solids 3% particulates/detritus 55% benthic invertebrates 40% small fish	Diets included the same portion of small fish (< 20 cm). The invertebrate portion of the diet in the BERA (worms and blue crab) was, in part, used as a surrogate for the consumption of benthic invertebrates and, to a lesser extent, particulates/detritus. In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.
Bass (largemouth and smallmouth)	10% worms 10% blue crab 80% small fish	20% benthic invertebrates 80% small fish	Diets included the same portion of small fish (< 13 cm) and invertebrates (represented by worms and blue crab in the BERA). In addition, sediment was included as an incidentally ingested component in the BERA, rather than as part of the overall diet.

BERA – baseline ecological risk assessment

LPRSA – Lower Passaic River Study Area

na – not applicable

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
Filter-feeding Fish				
Menhaden are opportunistic filter feeders as both juveniles and adults. Based on data from the mid-Atlantic and New England areas, menhaden consume the following, the proportions of which depend on prey availability (Rogers and van den Avyle 1989; Jeffries 1975): • Amorphous material (majority of prey) • Zooplankton (portion of the diet decreases as fish move from open waters to marshes) • Phytoplankton/diatom chains (if abundance is limited, may consume more detritus)	<i>Species was not evaluated in BERA; species was not selected as an ecological receptor for evaluation.</i>	Species was not evaluated in BERA; species was not selected as an ecological receptor for evaluation.	• particulates/detritus • phytoplankton/algae • zooplankton (representing copepods) <i>(quantitative data not available)</i>	Based on the available information and the fact that menhaden are opportunistic filter feeders, approximately one-half of the diet was assumed to be particulates/detritus, while the remainder was assumed to be phytoplankton/algae and zooplankton: • 50% particulates/detritus (water column) • 25% phytoplankton/algae • 25% zooplankton Calibration ranges are based on general ranges available from literature.
Both juveniles and adult menhadens are filter feeders. Food items include the following based on data from the East Coast (FishBase 2014): • 46–81% detritus • 0–36% phytoplankton • 18–20% zooplankton (copepods)			• 46–81% particulates/detritus • 0–36% phytoplankton/algae • 18–20% zooplankton (representing copepods)	
Small Forage Fish (mummichog)				
Empirical data are not available; reported prey items from various studies throughout the East Coast—including New Jersey, Connecticut, New England, and mid-Atlantic states (Abraham 1985; Allen et al. 1994; James-Pirri et al. 2001; Kneib 1986; Currin et al. 2003)—include the following: • Detritus • Algae • Small crustaceans (amphipods, tanaids, copepods, and ostracods) • Polychaetes • Insects (adult and larvae)	• worms (invertebrate and insect surrogate) <i>(quantitative data not available)</i>	Diet is composed of only prey for which empirical data were available from the LPRSA: • 100% worms (surrogate for benthic prey portion; also representing consumption of detritus, algae, and zooplankton) Small fish are not expected to compose a meaningful proportion of the diet.	• sediment solids • particulates/detritus • phytoplankton/algae • zooplankton (representing copepods) • benthic invertebrates <i>(quantitative data not available)</i>	Based on prey items listed in the literature and the assumption that small forage fish feed primarily on benthic invertebrates (with some incidental detritus ingestion), the representative bioaccumulation model compartments were assigned as follows: • 1% sediment solids • 15% particulates/detritus (near bottom) • 15% phytoplankton/algae • 4% zooplankton • 65% benthic invertebrates (consumed proportionally to LPRSA biomass) Small fish are not expected to compose a meaningful proportion of the diet.
Mummichogs are bottom feeders. Food items for juveniles and adults include the following (dietary proportions are not provided (FishBase 2014)): • Benthic invertebrates (benthic crustaceans, worms, mollusks) • Insects • Small fish	• worms (invertebrate and insect surrogate) • small fish <i>(quantitative data not available)</i>		• benthic invertebrates <i>(quantitative data not available)</i>	

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
Blue Crab				
A study of blue crab feeding habits conducted in a northern Florida estuary found that the diets of larger blue crab were directly influenced by prey availability. This study found the following average diets for blue crab larger than 6 cm (Laughlin 1982): • 73% benthic invertebrates (39% bivalves, 24% crab, 5% shrimp, 4% gastropods) • 14% small fish • 3% plant matter Other diet portions reported included various remains (animal, crab, and crustaceans), detritus, sand grains, and insect larva.	Species was not evaluated in the BERA for the dietary LOE; species was not selected as an ecological receptor for evaluation	Species was not evaluated in the dietary LOE in the BERA; species was not selected as an ecological receptor for evaluation.	Study was considered qualitatively because the crab evaluated were smaller than those evaluated in the LPRSA. • 1% sediment solids • 11% particulates/detritus • 73% benthic invertebrates • 14% small fish	Diet was based primarily on Hines et al. (1990), because the crab in that study most closely matched the size of crab modeled: • 2% sediment solids • 1% particulates/detritus (near-bottom) • 83% benthic invertebrates (consumed proportionally to LPRSA biomass) • 14% small fish Calibration ranges were based on the ranges reported by Hines et al. (1990) qualitative information from other literature studies.
A Raritan Bay study that evaluated the stomach contents of more than 400 blue crab reported the following average percents by volume (Stehlik et al. 1998). • 44% mollusks • 40% crabs • 1% polychaetes • 15% other unidentified matter The study noted that unlike in other studies, small fish were not found in the blue crab stomachs.			Study was considered qualitatively because the size class was not known. • 15% particulates/detritus • 85% benthic invertebrates	
A study conducted in the Rhodes River (Hines et al. 1990), an estuary of Chesapeake Bay, reported the following stomach content percentages for crabs that averaged 13 cm in length: • 2% sediment (range of 0–5%) • 1% detritus (range of 0–2%) • 67% invertebrates (range of 62–71%), composed primarily of clams and crabs • 12% fish (range of 4–17%) • 18% other digested animal tissue (range of 9–21%)	Species was not evaluated in the BERA; species was not selected as an ecological receptor for evaluation.	• 2% sediment solids • 1% particulates/detritus • 83% benthic invertebrates • 14% fish <i>(portion of diet composed of digested animal tissue divided proportionally between benthic invertebrates and fish)</i>		

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
Common Carp				
Carp are highly opportunistic feeders with a variable diet, the majority of which is composed of the following components (Maryland DNR 2007; Garcia-Berthou 2001; USGS 2010; Walburg and Nelson 1966): • Detritus • Algae/plants • Small benthic invertebrates Carp may also consume: • Insects • Small fish • Zooplankton		Prey are based on available LPRSA surrogate prey items (regional data not available). Diet could be composed of only prey for which empirical data were available from the LPRSA, as follows: • 82% worms (surrogate for zooplankton, insects and small benthic invertebrates; also representing consumption of detritus and algae) • 17% blue crab (surrogate for macroinvertebrates such as crayfish) • 1% fish ≤ 11 cm Diet composition for carp is uncertain given the large portion of dietary items with no empirical chemistry data from the LPRSA (e.g., detritus and plants).	• sediment solids • particulates/detritus • algae/plants • phytoplankton/zooplankton • benthic invertebrates • small fish <i>(quantitative data not available.)</i>	Selected diet for carp was based on general adult diet portions from the literature (regional data were not available). Diet also accounted for the benthic feeding habits of carp (i.e., high incidental sediment and detritus ingestion) and limited abundance of phytoplankton/algae in the LPRSA relative to other prey (i.e., portion of phytoplankton/algae was decreased relative to other more abundant prey items). The representative bioaccumulation model compartments were assigned the following prey portions: • 15% sediment solids • 25% particulates/detritus (near bottom) • 5% phytoplankton/algae • 54% invertebrates (consumed proportional to abundance in the LPRSA) • 1% small fish (benthic forage fish) Calibration ranges were based on general ranges available from literature.
Common dietary items for carp in Colorado waters include (FishBase 2014) (ranges based on percentages reported for three different areas): • 24–56% detritus (average = 37%) • 22–60% plants/benthic algae (average = 36%) • 0–2% zooplankton (average = 1%) • 4–11% insects (average = 8%) • 2–44% benthic invertebrates (e.g., crayfish) (average = 17%) • 0–2% fish (average = 1%)	• 73% other (detritus, plants/benthic algae) • 9% worms (zooplankton and insect surrogate) • 17% blue crabs (crayfish surrogate) • 1% fish		• 24–56% sediment solids plus particulates/detritus • 22–60% phytoplankton/algae (representing plants/benthic algae) • 0–2% zooplankton • 6–54% benthic invertebrates (representing benthic invertebrates and insects) • 0–2% fish	

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
Catfish				
General information regarding white catfish (California Fish Website 2013b) indicates that they are primarily carnivorous bottom feeders, although it is not uncommon for catfish to scavenge carrion or swim to the surface to feed on planktivorous fish. As they get larger, catfish shift to consuming fish and large invertebrates. Common dietary items include: • Amphipods • Shrimp • Insect larvae • Fish	• worms (amphipod and insect larvae surrogate) • blue crabs (shrimp surrogate) • small fish <i>(quantitative data not available.)</i>	Channel and white catfish were specifically modeled in the BERA. Based on general adult diet portions from the literature (regional data not available), plant consumption was assumed to be minimal in the LPRSA due to the limited presence of aquatic plants. A diet composed of only prey for which empirical data were available from the LPRSA is as follows: • 55% worms (surrogate for plants and insects also representing consumption of detritus and algae) • 5% blue crab (surrogate for mollusks and small crustaceans; also representing consumption of detritus and algae) • 40% small fish ≤ 13 cm Diet composition for catfish is uncertain given the large portion of dietary items with no empirical chemistry data from the LPRSA (e.g., plants).	• sediment solids and/or particulates/detritus based on scavenging feeding habits • benthic invertebrates (representing amphipods, shrimp, and insect larvae) • small fish <i>(quantitative data not available.)</i>	Channel and white catfish were modeled as a single compartment in the bioaccumulation model. Based on general adult channel and white catfish diet portions from the literature (regional data not available), accounting for benthic feeding habit, and assuming that phytoplankton/algae consumption is minimal in the LPRSA due to its limited presence relative to that of other available prey items, the representative bioaccumulation model compartments were assigned the following prey portions: • 5% sediment solids • 10% particulates/detritus (near bottom) • 2% phytoplankton/algae • 43% benthic invertebrates (consumed proportionally to abundance in the LPRSA) • 40% small fish (primarily benthic forage fish and some filter-feeding fish) Calibration ranges were based on general ranges available from literature.
Common dietary items for juvenile and adult white catfish from California rivers include (FishBase 2014): • 2% bryozoans • 2% insects • 41% benthic invertebrates (i.e., amphipods, crayfish, shrimp, and clams) • 41% small fish • 6% birds/mammals • 9% other Percentages are based on averages across seasons.	• 41% benthic invertebrates (i.e., worms [bryozoan, insect, amphipods surrogate] and blue crabs [crayfish and shrimp surrogate]) • 41% small fish • 15% other (birds/mammals and plants)		• 43% benthic invertebrates (representing insects, amphipods, crayfish, shrimp, and clams) • 41% small fishw • 17% other	
Based on qualitative stomach content analysis data, adult channel catfish have a varied diet (Wellborn 1988). Channel catfish are typically bottom feeders but will take some food from the surface. Common dietary items include: • Insects • Benthic invertebrates (snails, crayfish) • Green algae/aquatic plants/seeds • Small fish In “natural waters,” fish may make up as much as 75% of the diet of larger channel catfish (> 18 in. in length).	• worms (snail and insect surrogate) • blue crab (crayfish surrogate) • small fish • other (plants/algae) <i>(quantitative data not available.)</i>		• sediment solids • particulates/detritus • phytoplankton/algae • benthic invertebrates (representing snails, insects, and crayfish) • small fish <i>(quantitative data not available.)</i>	
The diet of juvenile channel catfish (approximately ≤ 20 cm) in the Lower Susquehanna River in Maryland (Weisberg and Janicki 1990) comprises: • 100% insects (40–60% caddisfly larvae; 25–55% midge larvae)	• 100% worms (insect surrogate) <i>(study not used because it looked only at juvenile catfish.)</i>		• 100% benthic invertebrates (insect surrogate) <i>(study not used because it looked only at juvenile catfish)</i>	
The diet of adult channel catfish in the Susquehanna River in Maryland (Fewlass 1980) includes: • 2% mollusks (Pelecypoda) • 2% crustacean (primarily <i>Callinectes sapidus</i>) • 43% small fish • 3% insects • 45% plants (generally intermingled with invertebrates, suggesting incidental ingestion) • 5% inorganic content (primarily small stones that were part of <i>Trichoptera</i> cases)	• 10% worms (mollusk, insect, and inorganic content surrogate) • 2% blue crab • 43% small fish • 45% other (plants)		• 5% particulate/detritus (representing inorganic content) • 45% phytoplankton/algae (representing plants) • 7% benthic invertebrates (representing mollusks, crustaceans, and insects) • 43% small fish	
Common dietary items for juvenile and adult channel catfish from Washington and California rivers include (FishBase 2014): • 0–1% insects • 25–73% small fish • 26–65% benthic invertebrates (crustaceans, mollusks, and amphipods) • 0–10% other (mammals)	• 26–65% worms (mollusk and amphipod surrogate) and blue crabs • 25–73% small fish		• 26–65% benthic invertebrates (representing mollusks, amphipods, and blue crabs) • 25–73% small fish	

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
White Perch				
Food items for white perch included (dietary proportions are not provided) (FishBase 2014): • Insects • Fish eggs/fish • Detritus • Benthic invertebrates (amphipods, annelids, mollusks) • Cladocerons	• worms (benthic invertebrate and insect surrogate) • small fish <i>(quantitative data not available.)</i>	Diet was determined based on regional data, including quantitative data from the Hackensack River and qualitative data from the Hudson River. A diet composed of only prey for which empirical data were available from the LPRSA is as follows: • 70% worms (surrogate for amphipods and other benthic invertebrates; also representing consumption of detritus, algae, and zooplankton) • 15% blue crab (surrogate for small crustaceans such as shrimp; also representing consumption of detritus, algae, and zooplankton) • 15% small fish ≤ 11 cm Diet is a best estimate of the year-round white perch diet using the available empirical data, although the diet could be highly variable depending on the season.	• detritus • zooplankton • benthic invertebrates • small fish <i>(quantitative data not available.)</i>	Selected diet for white perch was based on regional data, including quantitative data from the Hackensack River and qualitative data from the Hudson River. The portion of the diet identified as “unidentified material” was assigned primarily to benthic invertebrates; this portion was assumed to be composed of a small amount of detritus, phytoplankton, and zooplankton based on information from other studies that suggest that perch may consume small amounts of these items when they are available or incidentally while feeding. Although the Lake Erie study reported a high percentage of zooplankton in the white perch diet, zooplankton were assumed to represent a small percentage of the white perch diet in the Passaic River due to the relatively low abundance of zooplankton in the LPRSA. The representative bioaccumulation model compartments were assigned the following prey portions: • 5% particulates/detritus (near bottom) • 2% phytoplankton/algae • 3% zooplankton • 75% benthic invertebrates (primarily amphipods and shrimp) • 15% small fish (primarily benthic forage fish and some filter-feeding fish) Selected calibration ranges were quite wide based on the opportunistic foraging habits of white perch.
A Hackensack River (New Jersey) study reported the stomach contents for 78 white perch as percent dry weight (Weis 2005): • 23% amphipods • 17% shrimp • 17% fish • < 1% plant matter • 43% unidentified material	• 23% worms (amphipod surrogate) • 17% blue crab (shrimp surrogate) • 17% small fish • 43% other (unidentified material)		• 40% benthic invertebrates (representing amphipods and shrimp) • 17% small fish • 43% other (unidentified material)	
A Hudson River (New York) study reported the frequency of occurrence of prey items in white perch stomachs (Bath and O'Connor 1985). The following percentages are estimates based on mature white perch (> 11 cm in length): • 54% benthic invertebrates (6% annelid worms [seasonal range of 0–10%]; 40% amphipods [seasonal range of 25–75%]; 8% isopods [seasonal range of 0–25%]) • 1% insects (seasonal range of 0–5%) • 5% shrimp (seasonal range of 0–20%) • 4% fish / fish larvae (seasonal range not provided) • 9% plant matter (seasonal range of 0–25%) • 30% unidentified material (seasonal range not provided)	• high consumption of worms (invertebrate surrogate, primarily non-crustaceans) • low consumption of small fish <i>(study based on frequency of occurrence; data used qualitatively to assign prey portions)</i>		• high consumption of invertebrates (primarily non-crustaceans) • low consumption of small fish <i>(study based on frequency of occurrence; data used qualitatively to assign prey portions)</i>	
A York River (Virginia) study reported the approximate percent composition of white perch diet by weight for 12 mature white perch (McGrath 2005): • 85% decapods (68% crab [mud, blue, and fiddler crab], 17% shrimp) • 6% hydroid • 5% seahorse • 4% other benthic invertebrates (3% amphipods, 1% polychaetes)	• 85% blue crab (crab/shrimp surrogate) • 10% worms (invertebrate surrogate) • 5% other <i>(study not used to develop diet portions because available regional data determined to be more applicable)</i>		• 95% benthic invertebrates • 5% other <i>(study not used to develop diet portions because available regional data determined to be more applicable)</i>	
LPRSA qualitative stomach content material: • Amphipods	• worm (amphipod surrogate) <i>(quantitative site-specific data not available)</i>		• benthic invertebrates (representing amphipods) <i>(quantitative site-specific data not available)</i>	
A Lake Erie study reported dietary percentages (by volume) of stomach contents for 421 white perch collected from June through September in 1981 (Schaeffer and Margraf 1986): • 55% zooplankton (48% cladocerans [0–96%]; 7% copepods [0–20%]) • 7% benthic invertebrates (chironomids [0–14%]) • 38% fish (miscellaneous species [1–92%]) Value is the average for the four months; range is the range of value across the four months.	• 62% worm (invertebrate surrogate) • 38% small fish <i>(study not used to develop diet portions because available regional data determined to be more applicable)</i>		• 55% zooplankton (cladocerans and copepods) • 7% benthic invertebrates (chironomids) • 38% small fish <i>(study not used to develop diet portions because available regional data determined to be more applicabl.)</i>	

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
American Eel < 50 cm				
Dietary portion ranges for American eel < 50 cm in length from New Jersey streams were as follows (Ogden 1970): • 0–19% crustaceans • 72–100% insects • 0–22% fish	• 72–100% worms (insect surrogate) • 0–19% blue crab (crustacean surrogate) • 0–22% small fish	Diet was based on general ranges from regional (New Jersey) data for eel < 50 cm in length. A diet composed of only prey for which empirical data were available from the LPRSA is as follows: • 80% worms (insect surrogate) • 10% blue crab (surrogate for small crustaceans) • 10% small fish ≤ 13 cm	• 0–100% benthic invertebrates (representing crustaceans and insects) • 0–22% small fish	Selected diet for American eel was based on general ranges from regional (New Jersey) data for eel > 50 cm, as well as on incidental ingestion of sediment solids and particulates/detritus. The representative bioaccumulation model compartments were assigned the following prey portions: • 2% sediment solids • 3% particulates/detritus (near bottom) • 85% benthic invertebrates (primarily crustaceans but also smaller invertebrates) • 10% small fish (primarily forage fish and some filter-feeding fish) Calibration ranges were based on general ranges from the literature.
Dietary portion ranges for American eel < 25 cm in length from the James River, a tributary to Chesapeake Bay, were as follows (Lookabaugh and Angermeier 1992): • 95% invertebrates • 5% crayfish	• 95% worms (invertebrate surrogate) • 5% blue crab (crayfish surrogate) <i>(dietary data not used because data do not include fish between 25 and 50 cm in length)</i>		• 100% benthic invertebrates	
Common dietary items for stocked American eel < 50 cm in length in Lake Champlain (Vermont) included (FishBase 2014): • 2% amphipods • 2% mollusks • 33% insects • 30% benthic crustaceans (decapods) • 1% plants • 32% fish	• 37% worms (amphipod, mollusk, and insect surrogate) • 30% blue crab • 32% small fish		• 67% benthic invertebrates (representing amphipods, mollusks, decapods, and insect surrogate) • 32% small fish	
American Eel ≥ 50 cm				
Dietary portion ranges for American eel > 50 cm in length from New Jersey streams were as follows (Ogden 1970): • 20–40% crustaceans • 0–40% insects • 20–60% fish	• 0–40% worms (insect surrogate) • 20–40% blue crab (crustacean surrogate) • 20–60% small fish	Diet was based on general ranges from regional (New Jersey) data for eel > 50 cm. A diet composed of only prey for which empirical data were available from the LPRSA is as follows: • 35% worms (surrogate for small invertebrates; also representing consumption of detritus) • 25% blue crab (surrogate for crayfish/ small crustaceans; also representing consumption of detritus) • 40% small fish ≤ 20 cm	• 20–80% benthic invertebrates (representing crustaceans and insects) • 20–60% small fish	Selected diet for American eel was based on general ranges from regional (New Jersey) data for eel > 50 cm, as well as on incidental ingestion of sediment solids and particulates/detritus. The representative bioaccumulation model compartments were assigned the following prey portions: • 2% sediment solids • 3% particulates/detritus (near-bottom) • 55% benthic invertebrates (primarily crustaceans but also smaller invertebrates) • 40% small fish (primarily benthic forage fish and some filter-feeding fish) Calibration ranges were based on general ranges from the literature.
Dietary portion ranges for American eel > 37 cm in length from the James River, a tributary to Chesapeake Bay, were as follows (Lookabaugh and Angermeier 1992): • < 5% invertebrates • > 95% crayfish	• 5% worms (invertebrate surrogate) • 95% blue crab (crayfish surrogate) <i>(dietary data not used because data include fish smaller than 50 cm in length)</i>		• 100% benthic invertebrates	
Common dietary items for stocked American eel > 50 cm in length from Lake Champlain (Vermont) included the following (FishBase 2014) • 1–6% amphipods • 3–6% mollusks • 25–30% insects • 18–45% benthic crustaceans (decapods) • 1% plants • 22–43% fish	• 29–42% worms (amphipod, mollusk, and insect surrogate) • 18–45% blue crab • 22–43% small fish		• 47–87% benthic invertebrates (representing amphipods, mollusks, decapods, and insect surrogate) • 22–43% small fish	

Table 7. Rationale for BERA and bioaccumulation model fish prey composition assumptions

Dietary Information and Prey Portions from Literature	BERA Prey Portions		Bioaccumulation Model Prey Portions	
	Options for BERA Parameters	Selected BERA Prey Portions/Rationale	Prey Portion Options	Selected Diet and Rationale
Bass (smallmouth and largemouth)				
A study of largemouth bass in the Hudson River (New York) provided the following percentage ranges (USEPA 2000). 10–25% invertebrates (most commonly occurring were crayfish, amphipods, isopods, cladocerans, cyclopoid copepods, ostracods, and some chironomid larvae) 75–90% fish	10% worms (benthic invertebrate surrogate) 10% blue crab (crayfish surrogate) 80% small fish	Diet was based on regional data from the Hudson River. A diet composed of only prey for which empirical data were available from the LPRSA is as follows: 10% worms (surrogate for amphipod, isopod, and other invertebrates) 10% blue crab (surrogate for crayfish/small crustaceans) 80% small fish ≤ 13 cm	20% (10–25%) benthic invertebrates 80% (75–90%) small fish	Selected diet for bass was based on regional data for largemouth bass from the Hudson River. The representative bioaccumulation model compartments were assigned the following prey portions: 20% benthic invertebrates (primarily crayfish and a small portion of amphipods and mollusks) 80% small fish (filter-feeding and benthic forage fish) Broad calibration ranges for the two food items were selected to reflect the known opportunistic nature of bass feeding habits (which may vary greatly depending on season and prey availability).
A study of smallmouth bass in Lake Sammamish (Washington State) reported the frequency of occurrence of prey in bass stomachs as follows (Pflug and Pauley 1984): 0–19% aquatic insects 15–42% crayfish 50–71% fish Ranges were based on bass aged two through five years	- worms (insect surrogate) - blue crab (crayfish surrogate) - small fish <i>(dietary portions not based on study because regional data available)</i>		- benthic invertebrates (insect and crayfish surrogate) - small fish <i>(dietary portions not based on study because regional data available)</i>	
A Willamette River study of both largemouth and smallmouth bass reported the percentage (wet weight) of stomach contents as follows (Pribyl et al. 2005): - Smallmouth bass (n = 15): 90% fish 5% crayfish 5% shrimp - Largemouth bass (n = 5): 100% crayfish	10–100% blue crab (crayfish/shrimp surrogate) 0–90% small fish <i>(dietary portions not based on study because regional data available)</i>		10–100% benthic invertebrates (crayfish/shrimp surrogate) 0–90% small fish <i>(dietary portions not based on study because regional data available)</i>	
Common dietary items for juvenile and adult largemouth bass (16 to 49 cm in length) from California rivers include the following (FishBase 2014): 16% benthic invertebrates (crayfish) 51% amphibians 33% small fish	16% blue crab (crayfish surrogate) 33% small fish 51% other (amphibians) <i>(dietary portions not based on study because regional data available)</i>		16% benthic invertebrates (representing decapods, other crustaceans, oligochaetes, and insect surrogate) 33% small fish 51% other (amphibians) <i>(dietary portions not based on study because regional data available)</i>	
Common dietary items for adult smallmouth bass from Pennsylvania, Minnesota, and California rivers include the following (FishBase 2014): 0–6% detritus 1–92% insects 2–21% decapods 0–9% other benthic invertebrates (other crustaceans and oligochaetes) 0–78% fish	0–92% benthic invertebrates (representing, crustaceans, oligochaetes, and insect surrogate) 2–21% blue crab (decapod surrogate) 0–78% small fish <i>(dietary portions not based on study because regional data available)</i>		0–6% detritus 0–92% benthic invertebrates (representing decapods, other crustaceans, oligochaetes, and insect surrogate) 0–78% small fish <i>(dietary portions not based on study because regional data available.)</i>	

BERA – baseline ecological risk assessment
LOE – line of evidence
LPRSA – Lower Passaic River Study Area

4 Small Fish Abundance Estimates

As was done for the benthic invertebrate feeding groups (Appendix D), available data from the LPRSA were evaluated to better understand the proportions of small fish present in the LPRSA. These data were used to estimate the relative contributions of the three small fish feeding groups within the LPRSA in order to assign relative dietary portions to higher-trophic-level species (blue crab and fish) that consume small fish in the bioaccumulation model.

Given the opportunistic feeding nature of most fish, LPRSA fish are generally expected to consume prey types relative to their abundance and availability. The small fish compartment modeled as part of the bioaccumulation model included the following:

- ◆ **Small filter-feeding fish** – Small filter-feeding fish feed primarily in the water column. The most common species in this category included silversides (both Atlantic and inland), Atlantic menhaden, and gizzard shad.
- ◆ **Small benthic forage fish** – Small benthic forage fish feed primarily along the bottom of the waterway. The most common species in this category included mummichog, killifish (both banded and striped), various types of sunfish (e.g., pumpkinseed and bluegill), and shiner species.
- ◆ **Small American eel** – Small eel were defined as those less than 50 cm in length.

However, unlike benthic invertebrates – for which LPRSA data were available from sampling efforts specifically designed to understand the composition of the benthic invertebrate community – fish were collected using a variety of sampling methods that differed in their rates of success. Thus, it is important to recognize the uncertainty associated with the small fish percentages used to parameterize the model.

4.1 PERCENTAGES FOR DIETS OF UPPER TROPHIC LEVEL SPECIES

In developing the percentages for each of the modeling areas, there were two key considerations:

- ◆ **Inclusion of data from all sampling methods** – A key consideration when developing percentages was whether data from all collection methods should be included in the analysis. Efforts were made to look at data by collection method, but ultimately, it was determined that decisions regarding which collection methods to include vs. exclude from the evaluation were just as uncertain as including data from all collection methods.
- ◆ **Biomass vs. abundance data** – In evaluating the use of biomass vs. abundance data for developing percentages of relative proportions of small fish present,

abundance data were selected because fish weight data were not available for all of the fish collected as part of the fish community surveys.

Based on these decisions, Figure 10 presents a summary of the breakdown of small fish abundance by river mile in the LPRSA.

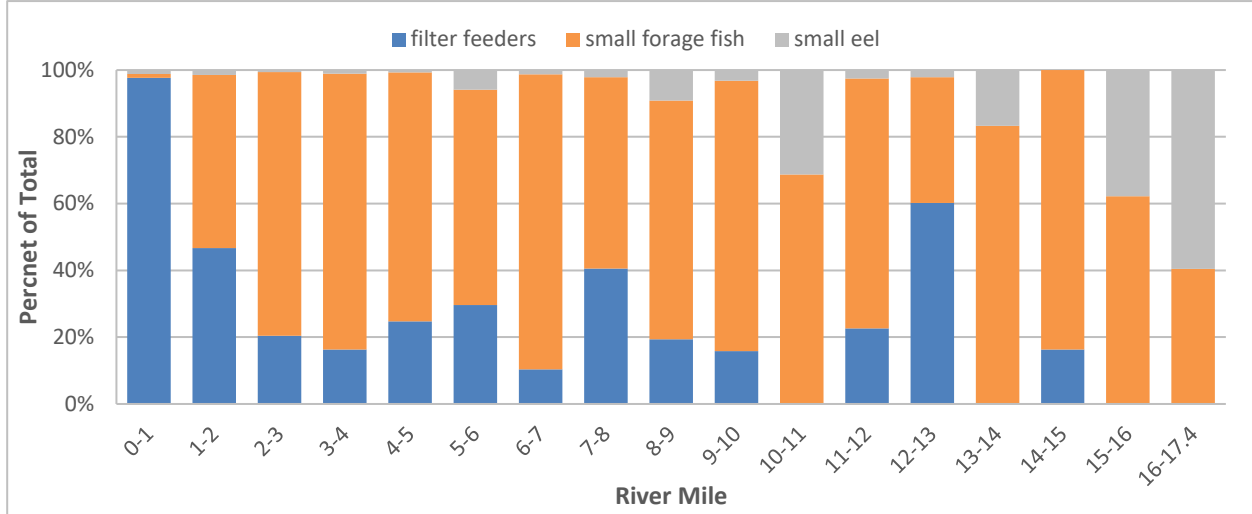


Figure 10. Abundance of small fish in the LPRSA by river mile

Figure 10 shows that, with some exceptions (e.g., RM 12 to RM 13), the proportion of small filter-feeding fish generally decreases with increasing river mile, whereas the percentage of small American eel generally increases with increasing river mile; very small numbers of small American eel were observed in the lower portions of the LPRSA. The overall percentage of small forage fish is relatively consistent throughout the LPRSA, generally ranging from about one-half to three-quarters of the total small fish community within each river mile segment. Using the information in Figure 10, percentages for each modeling area were calculated as the average across the river miles included in each modeling area (Table 8). In addition, ranges were developed using the percentages for each river mile within the modeling area.

Table 8. Summary of abundance by modeling area

Species Category	RM 0 to RM 6		RM 6 to RM 14.7		RM 14.7 to RM 17.4	
	Average	Range	Average	Range	Average	Range
Small filter feeding fish	39%	16–98%	21%	0–60%	0%	0–5% ^a
Small forage fish	59%	1–83%	71%	38–62%	51%	41–62%
Small American eel	2%	1–6%	8%	0–31%	49%	38–59%

Note: Data were summarized by river mile, then the average and range were calculated for each modeling area.

^a Although the maximum percentage of small filter-feeding fish was < 1% in this modeling area, a range of 0 to 5% was assigned to account for uncertainties associated with the limited types of collection methods that could be used in this area.

RM – river mile

4.2 COMPARISON WITH OTHER STUDIES

To provide further context for how the abundance percentages developed for the LPRSA compare to other regional data, a review of several fish community studies that evaluated fish abundance in rivers similar to the Passaic River are summarized herein:

- ◆ **Delaware River (Weisberg et al. 1996)** – This study, which summarized results of annual seining on the Delaware River from 1980 to 1996, described several species of filter-feeding fish (e.g., alewife, American shad, gizzard shad, blueback herring, and common bay anchovy) as being among those most commonly caught in the river.
- ◆ **New England estuary (Hoff and Ibara 1977)** – This study evaluated the fish population in a New England estuary over a period of two years; it found that the dominant species included both small forage fish (e.g., mummichog, striped killfish, four spine stickleback, and sheepshead minnow) and small filter-feeding fish (e.g., Atlantic silverside). This study also noted that some species (e.g., white perch and Atlantic menhaden) were present in the estuary in large numbers during certain times of the year.
- ◆ **Mystic River in Boston (Haedrich and Haedrich 1974)** – The fish community results presented in this study showed that the most commonly collected species of small fish were filter feeders (e.g., alewife, herring, and smelt).
- ◆ **Passaic River (Iannuzzi and Ludwig 2004)** – This study reported the results of fish community surveys conducted in the fall of 1999 and spring of 2000 on the lower 7 miles of the LPRSA. Of the fish collected, mummichog were reported to be the most frequently caught (over 75% of the total catch); filter-feeding fish (e.g., menhaden, gizzard shad, and silversides) were found to be less abundant (less than 15% of the total catch).

Many of the fish most frequently caught in the LPRSA (e.g., killfish, silverside, and mummichog) were also reported to be abundant in other studies of the Passaic River and other similar rivers. Small forage fish in the LPRSA were found to make up 51 to 72% of the small fish abundance; they were also found to be the dominant small fish present in the New England estuary and in a previous study on the lower portion of the LPRSA. Filter-feeding fish in the LPRSA were found to make up smaller portions (0 to 39%) of the small fish abundance compared to portions reported for the Delaware and Mystic Rivers. As would be expected, there is variability among these rivers on the relative portions of small fish abundance (some of which can be attributed to sampling methods and differences in geographic and riverine characteristics affecting ecological habitats). However, these studies are useful in helping to provide further evidence that using the catch results from the LPRSA is a reasonable method of

estimating abundance (and thus developing dietary percentages for the upper-trophic-level species).

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